Analyses and Assessment of the Aerodynamic Behavior of Tests with High Swept Aircraft in DNW Wind Tunnels

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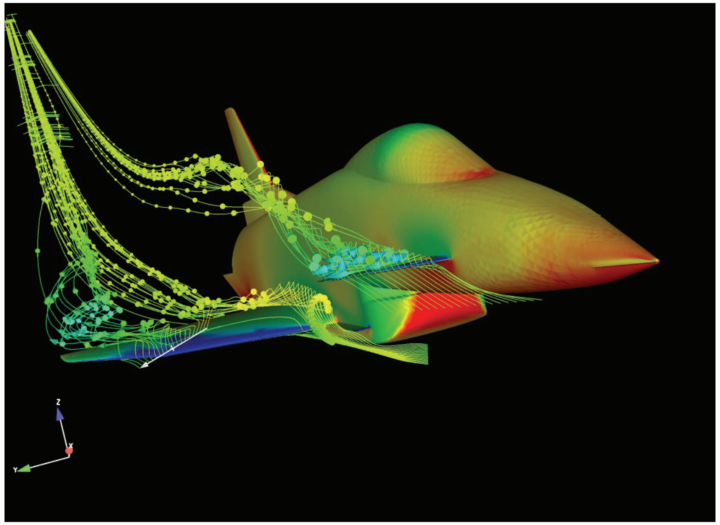
European Windtunnel Association
Demo-Workshop “Dynamic Wind Tunnel Testing”, April 28th 2009

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Motivation and Background
Simulation of maneuvering fighter aircraft

- Delta wing configurations
- Complex vortex dominated flow field
- Wide range of AOA
- High agility
- Unsteady aerodynamics
- Unstable configurations
- Nonlinear aerodynamic behavior



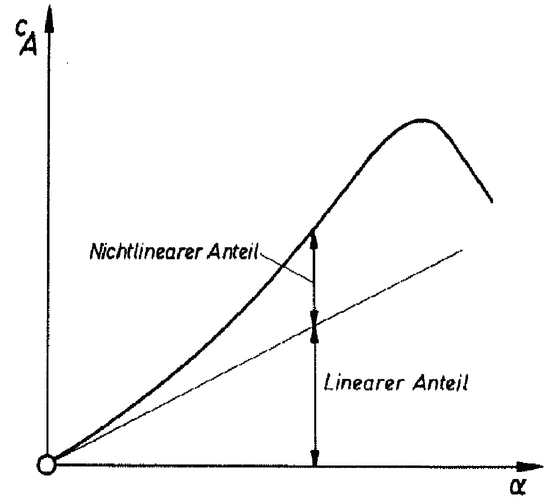
Objectives

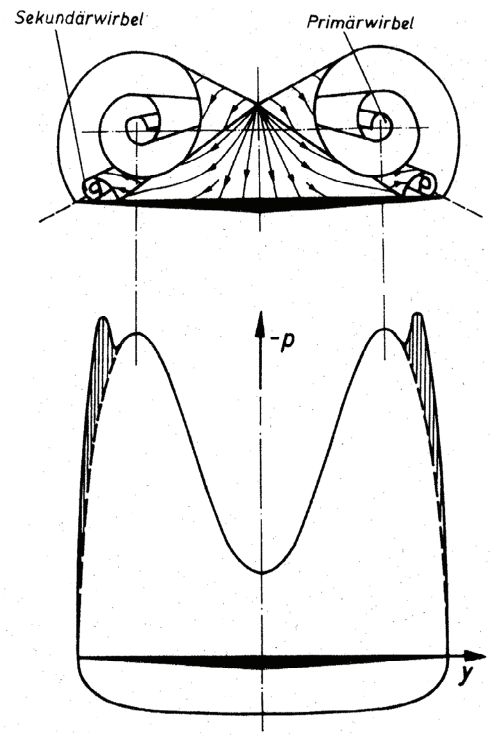
- Access of validation data for numerical static and dynamic computer code validation
- Knowledge approach of the aerodynamic behavior of configurations with vortex dominated flow field

Requirements

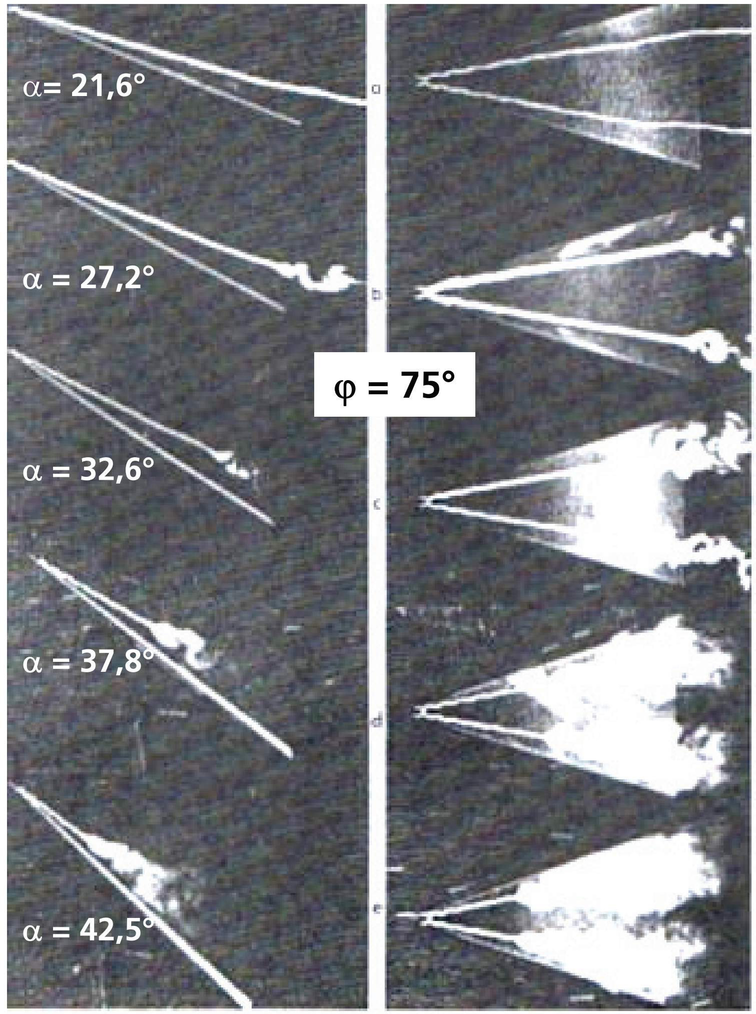
- High accuracy of wind tunnel data
  - Position of the model
  - Forces and moments
  - Pressure data
  - PIV data
- Entire image of the test conditions
  - Wind tunnel (On flow conditions, wall corrections,……..)
  - Wind tunnel model (Transition, model surface, control surfaces, model support,….)

Delta wing aerodynamics
Lift and AoA





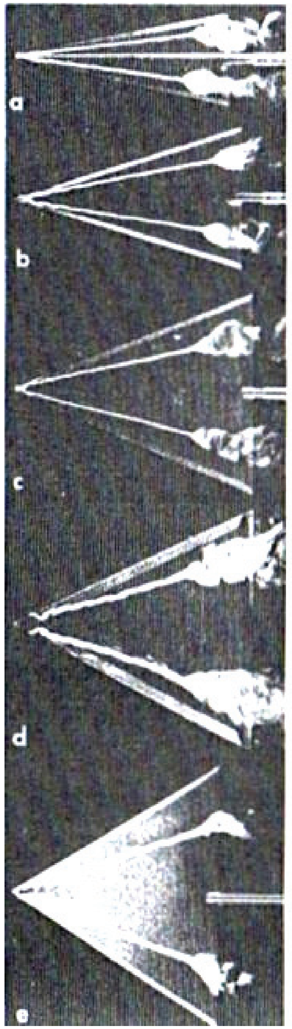
Quelle: D. Hummel



Quelle: Werle

Delta wing aerodynamics

Vortex topology and vortex stability (Vortex break down)



φ **= 80°** α **= 35°**

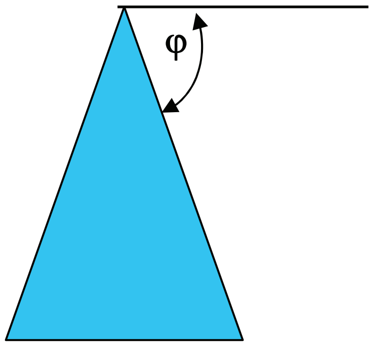
φ **= 75°** α **= 32,5°**

φ **= 70°** α **= 27,5°**

$\Lambda\uparrow$ α (Vortex breakdown at TE) $\downarrow$

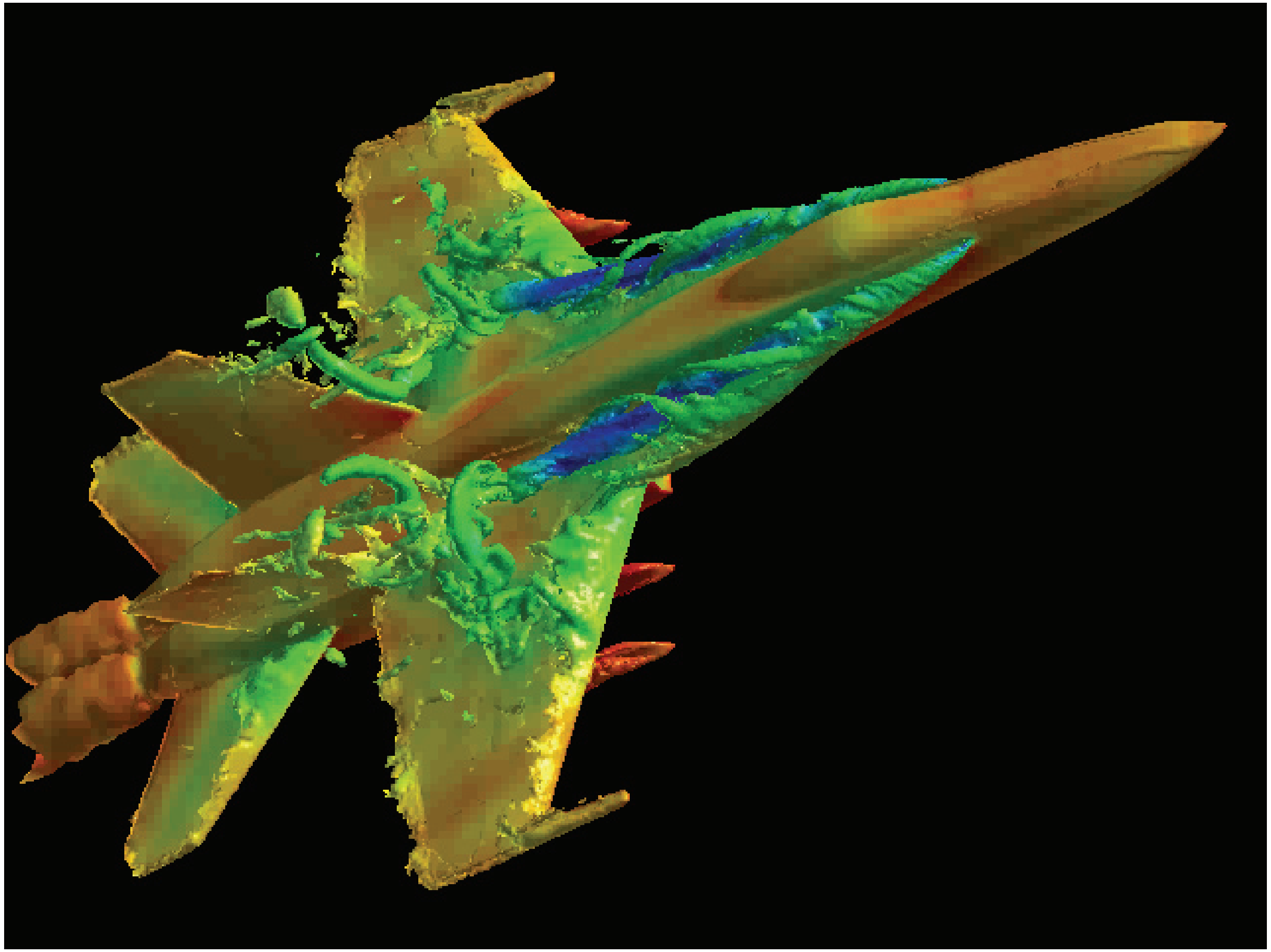
φ **= 65°** α **= 22,5°**

φ **= 60°** α **= 13°**



Quelle: Werle

Delta wing aerodynamics
F-18: Vortex topology and vortex stability (Vortex break down)

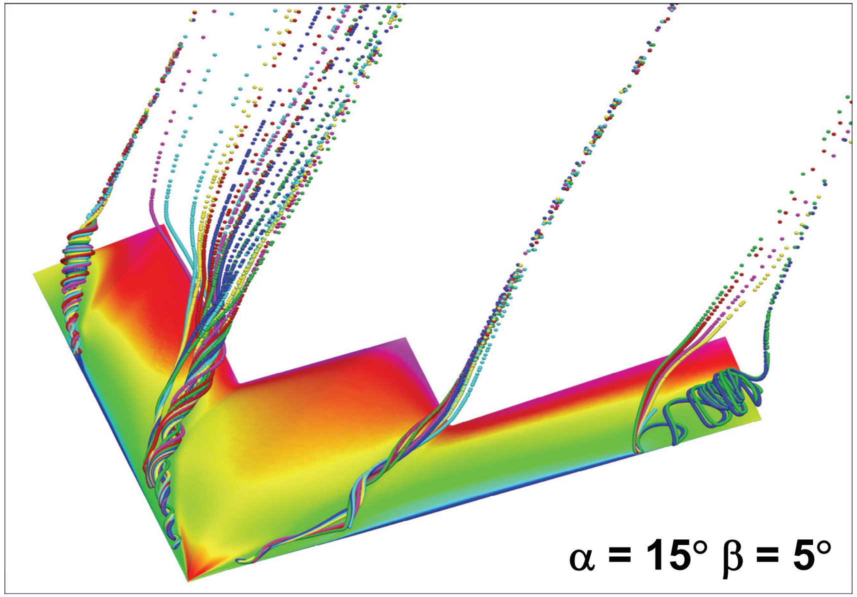


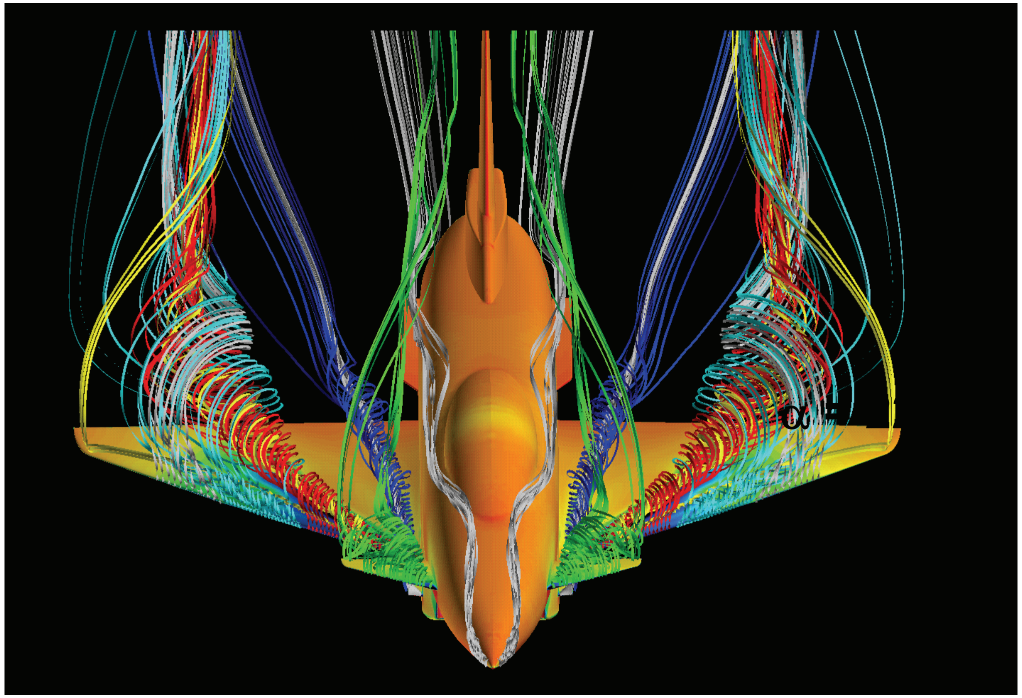
Quelle: S. Morton
USAF Academy
CFD Cobalt

Delta wing aerodynamics
Vortical flow topology

UCAV

X-31





DLR TAU-Code

Delta wing aerodynamics
F-18: Vortical flow topology at LE strake

Simulation of maneuvering fighter aircraft

Non-dimensional parameters

Reduced frequency and Reynolds number

$$\omega^* = 2\pi \cdot f \cdot c_{ref} / V_\infty$$

M (real)	V∞ [m/s] (real)	f (real) [Hz]	f (NWB)(M=0.15) [Hz]	f (NWB)(M=0.17) [Hz]
0.3	102.99	0.2	0.68	0.82
0.4	137.32	0.5	1.27	1.53
0.5	171.65	1	2.04	2.45
0.6	205.98	1.5	2.55	3.06
0.7	240.30	2	2.91	3.50

f(NWB, TWG) higher if keeping M(real)=konst.

M (real)	V∞ [m/s] (real)	f (real) [Hz]	f (TWG)(M=0.3) [Hz]	f (TWG)(M=0.4) [Hz]	f (TWG)(M=0.5) [Hz]
0.3	102.99	0.2	3.50	4.67	5.83
0.4	137.32	0.5	6.56	8.75	10.94
0.5	171.65	1	10.50	14.00	17.50
0.6	205.98	1.5	13.13	17.50	21.88
0.7	240.30	2	15.00	20.00	25.00

$$R_{c_{ref}} = c_{ref} \cdot V_\infty / \nu$$

M		Re (TWG)
0.3		1.43E+06
0.4		1.91E+06
0.5		2.39E+06
0.6		2.87E+06
0.7		3.34E+06
M		**Re (TWG)**
0.15		1.74E+06
0.17		2.09E+06

ω^* : Reduced frequency
R : Reynolds number
f : Frequency
c_{ref} : Reference length
V_∞ : on flow velocity
ν : kinematic viscosity

Wind Tunnel Models

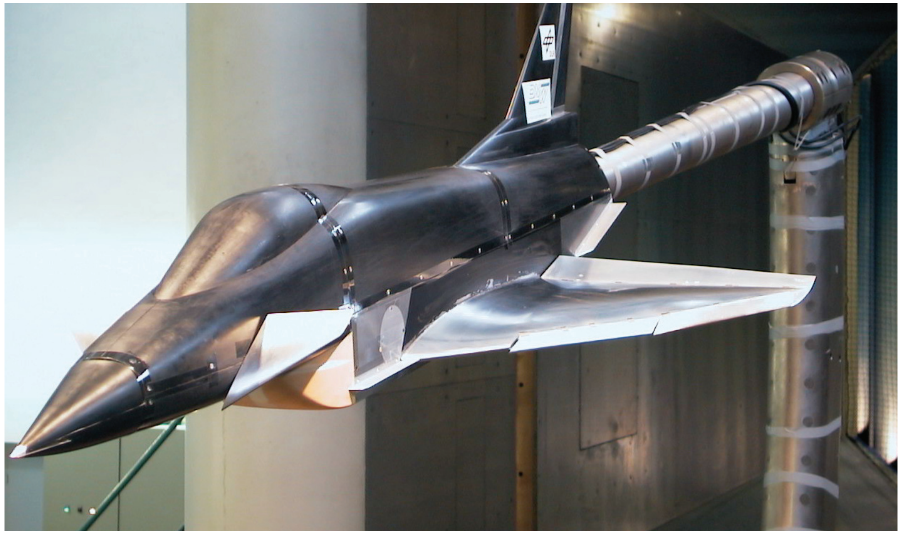
X-31 Low speed wind tunnel models (Scale 1:7)

X-31 1:7 CFRP model:

- total weight: 10 kg
- control devices:
  leading- /trailing-edge flaps,
  rudder, canard
- manually adjustable

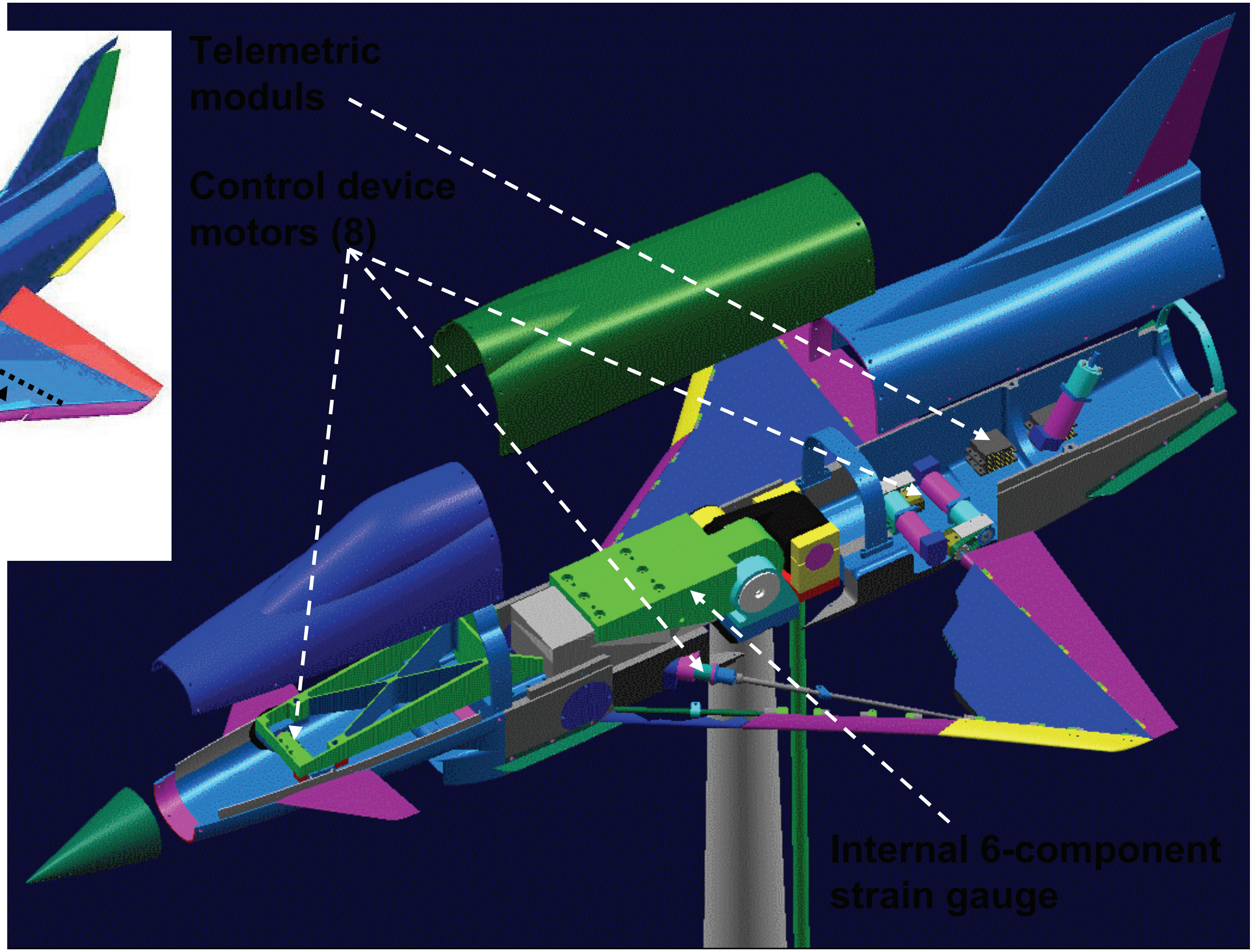
X-31 1:7 remote-control model:

- total weight: 120kg
- CFRP fuselage, steel wing and aluminum made control devices
- control devices:
  leading-/trailing-edge flaps, rudder
  8 internal servo motors
  (up to 200°/s)



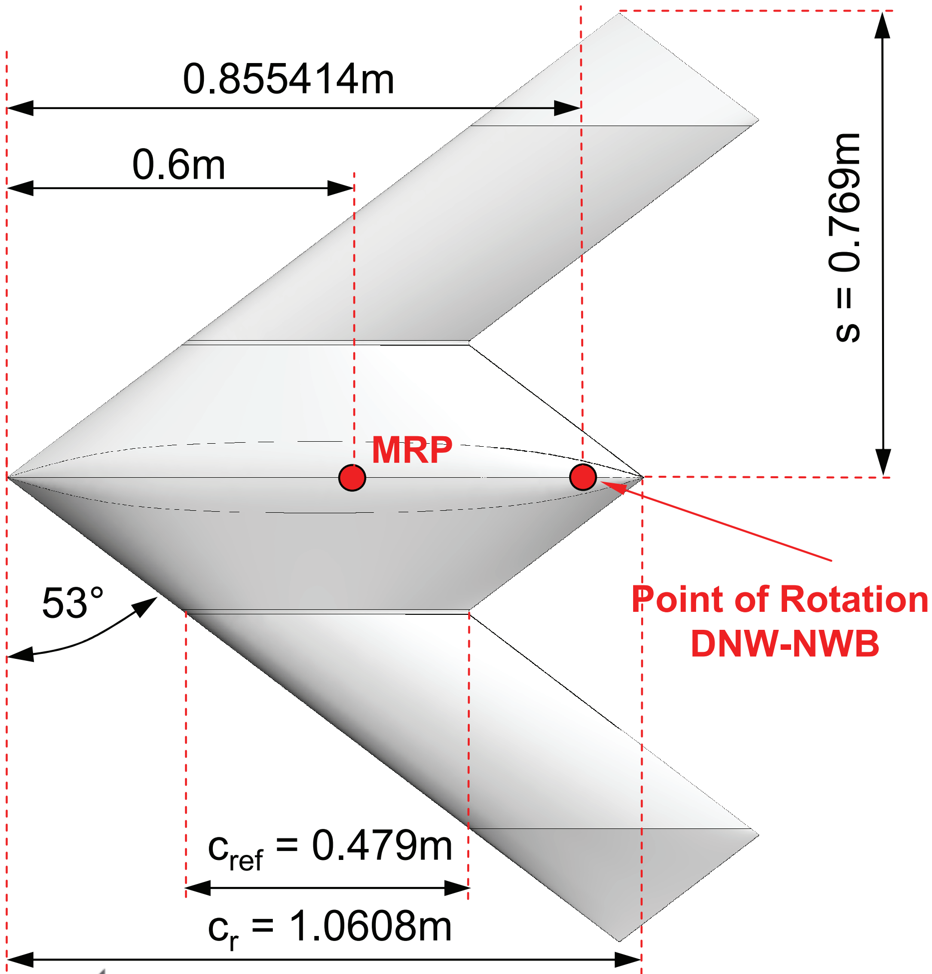
Wind Tunnel Models
X-31 model equipment

piezo-resistive pressure sensors at 60% and 70% chord length (50)

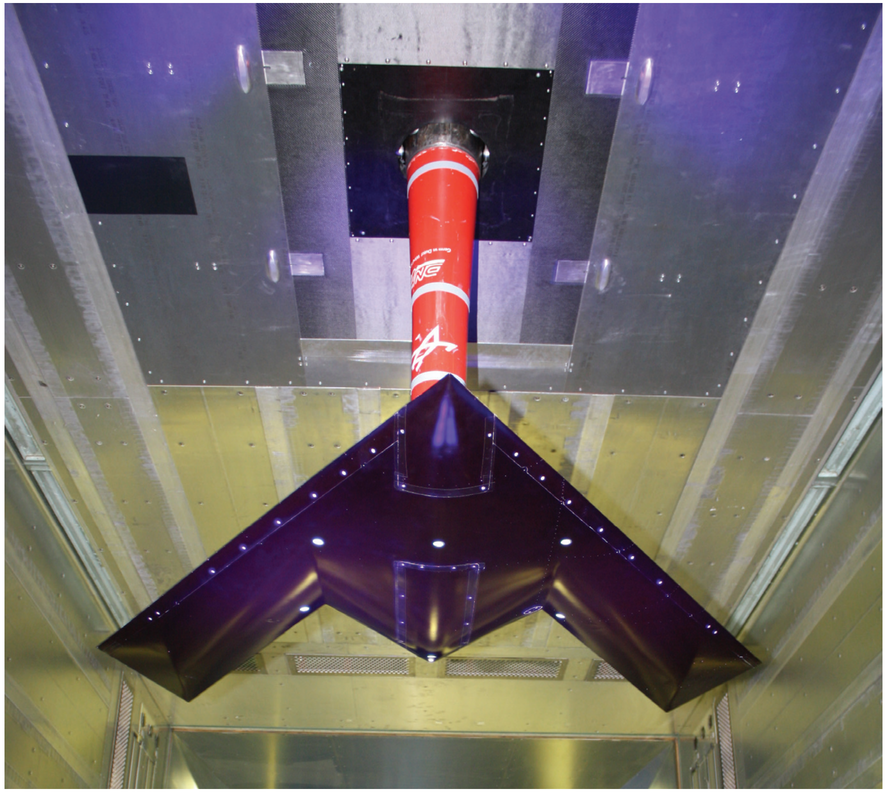


Wind Tunnel Models

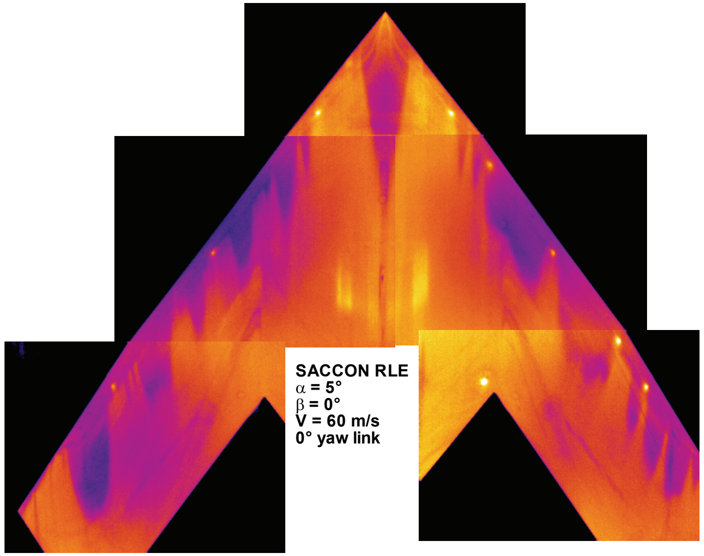
UCAV low speed wind tunnel model DLR-F17
(NASA-SACCON) (Scale 1:8)

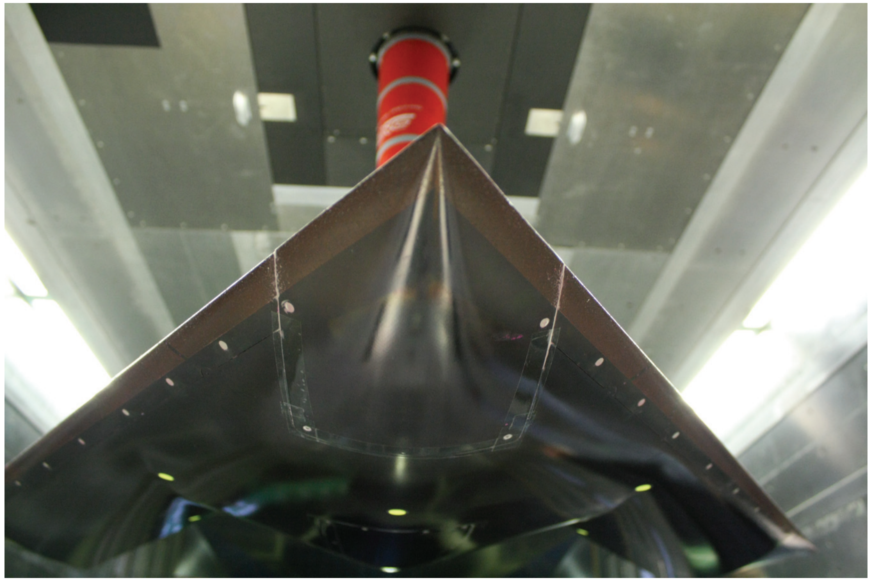


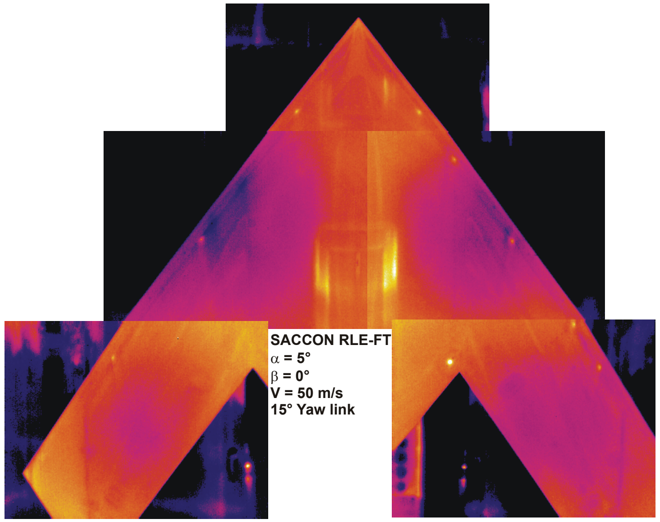
- total weight: 10 kg (CFRP)
- 250 pressure tubes

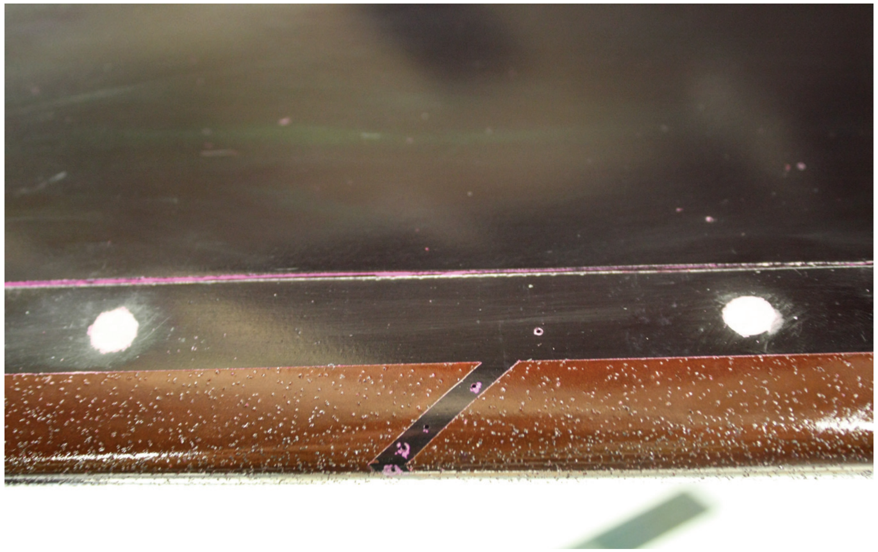


Wind Tunnel Models
Flow Transition





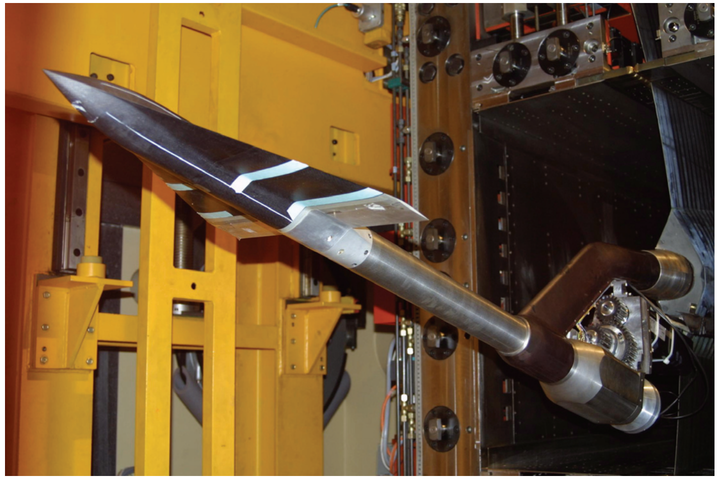




Wind Tunnel Models
Wind tunnel setup
High speed wind tunnel tests (AeroSUM model)

Delta-wing-configuration with trailing-edge flaps

- Internal 6-component piezo-balance
- Piezo-resistive pressure sensors at 60% and 80% chord length
- Control device velocity up to 300°/s



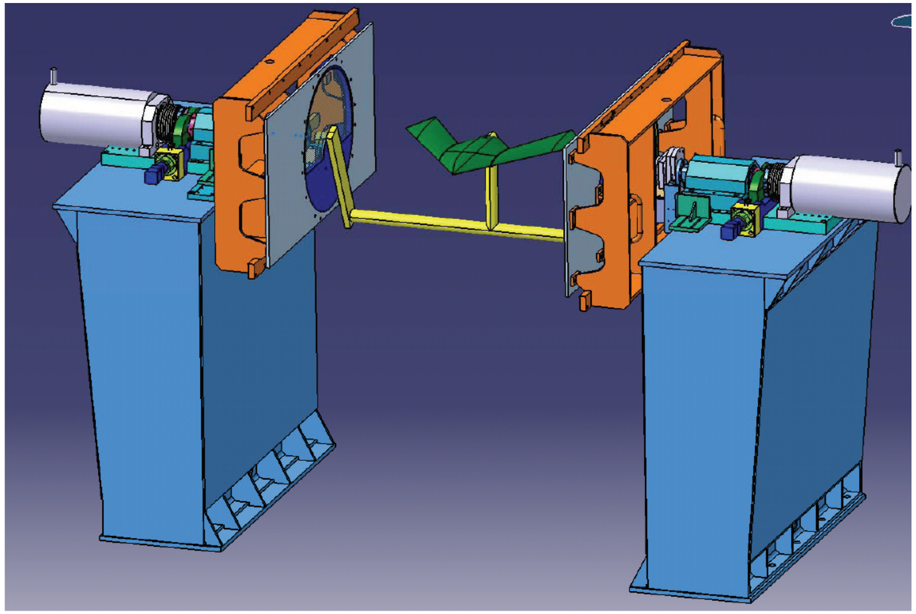
DNW-TWG Tests

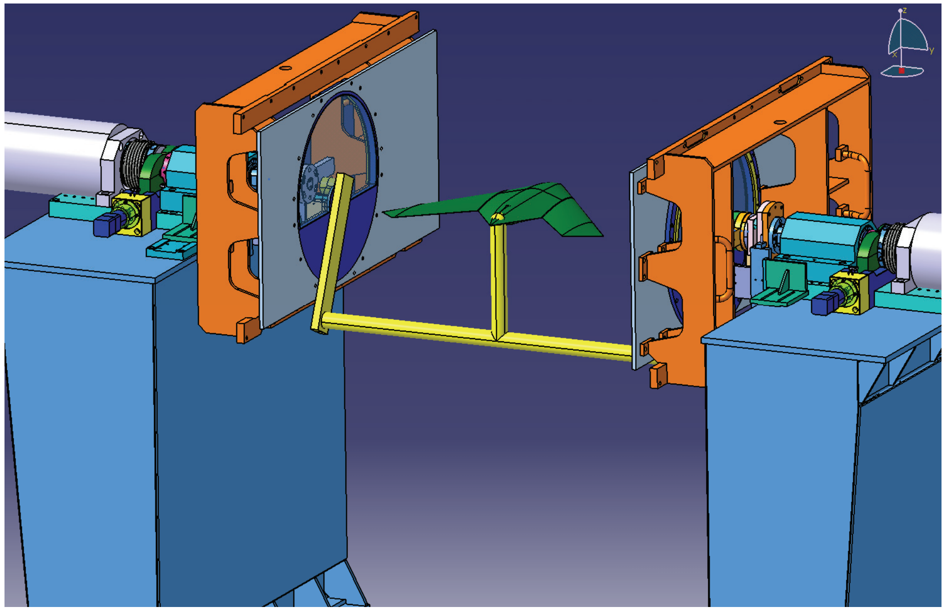
- Forced-to-roll motion
- Free-to-roll motion
  - Anti-symmetric loads
  - Forced by flap defection

Wind Tunnel Models
Wind tunnel setup
High speed wind tunnel tests

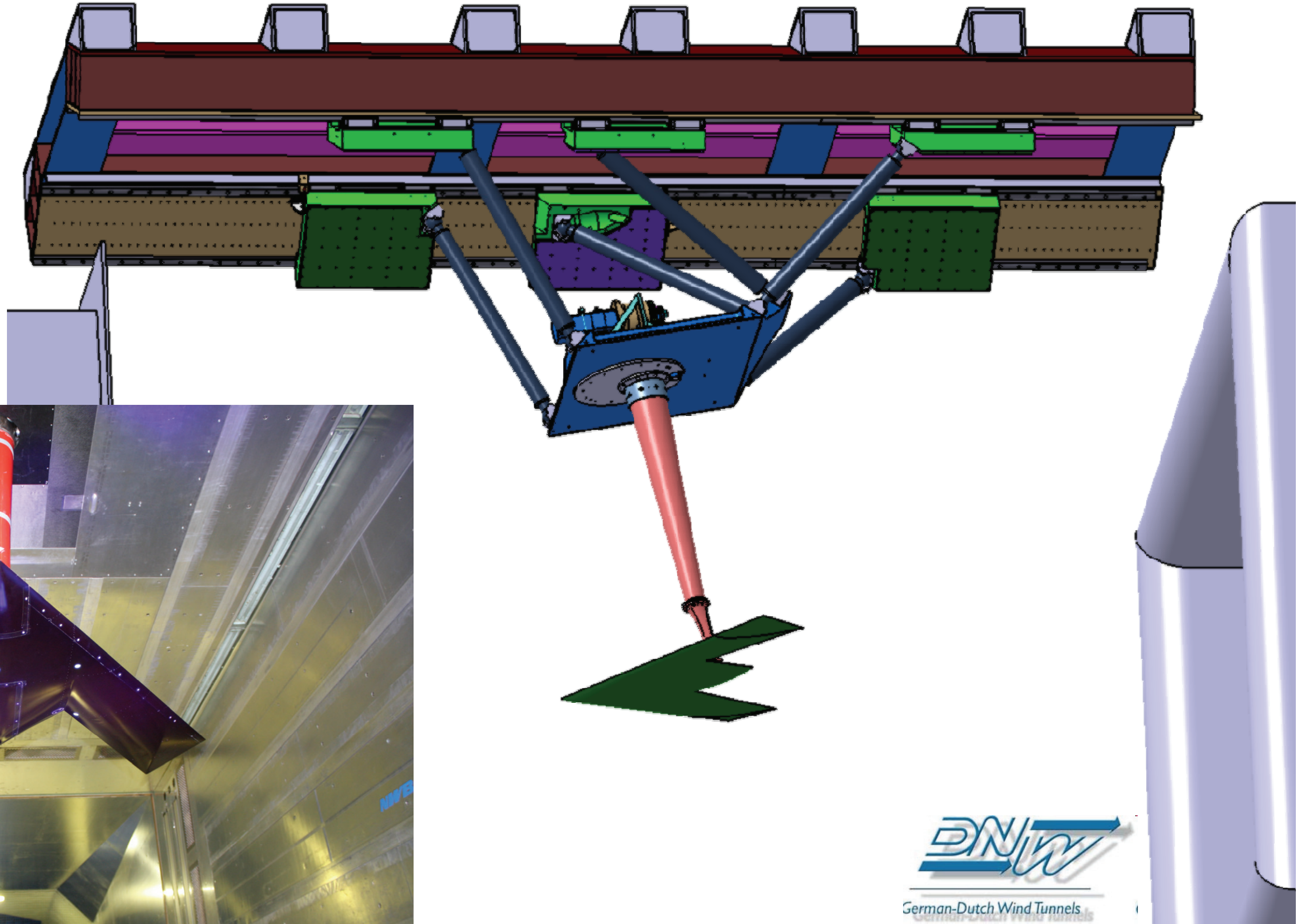
DLR-F17 TWG model

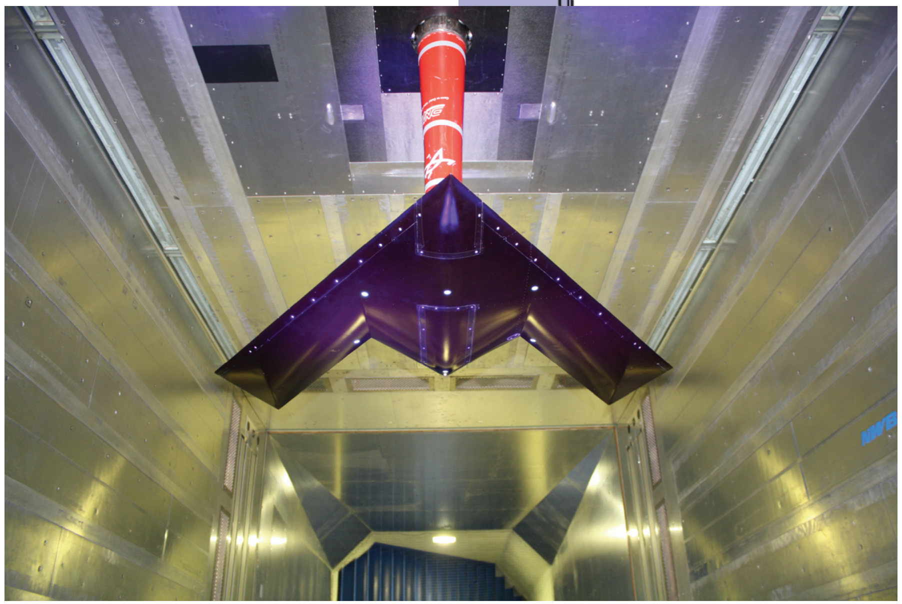
- Internal 6-component balance
- Piezo-resistive pressure sensors
- Pitch motion support





Wind tunnel setup
DLR-F17, NASA-SACCON model





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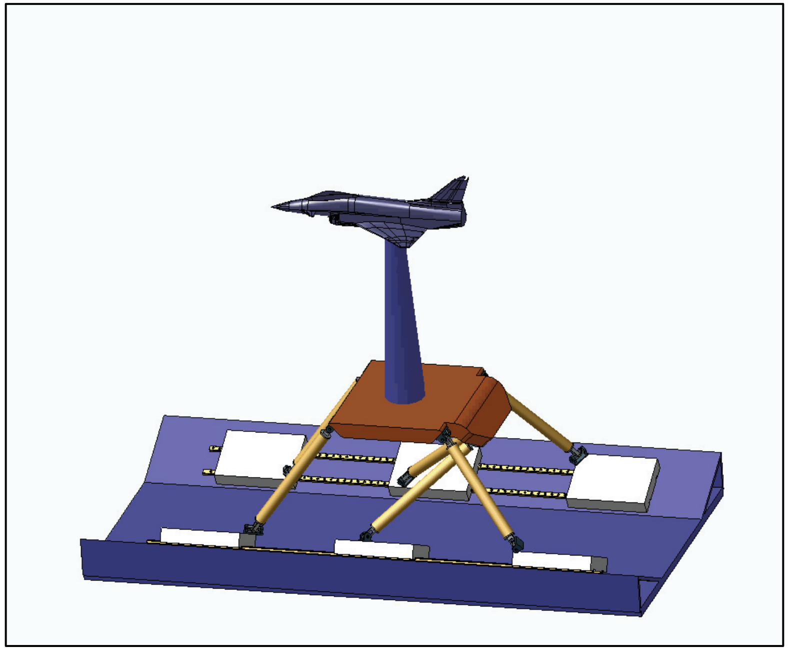
Experimental Approach
X-31 on MPM - "Model Positioning Mechanism"

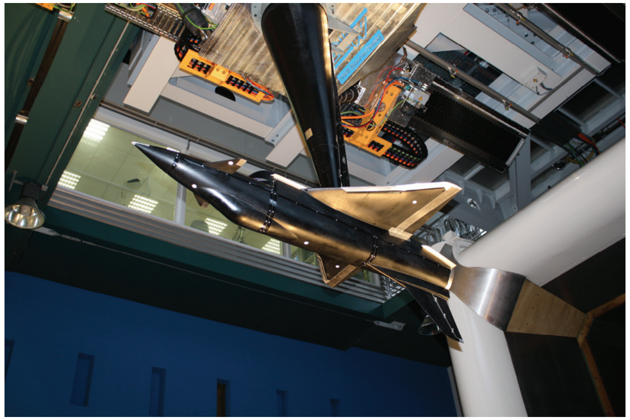
- Synchronized, dynamic similar movement of model and control devices in comparison to flight tests



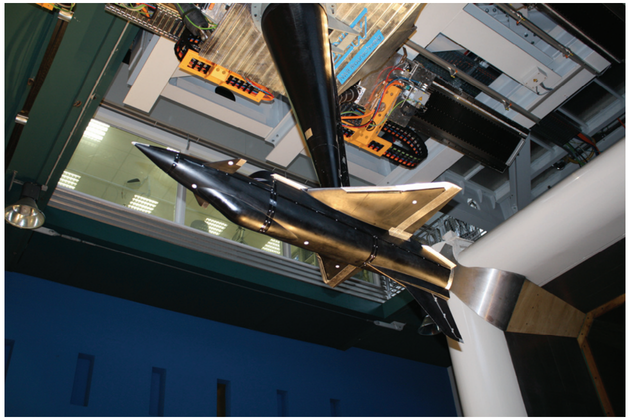
- Parallel kinematics
- Steward platform connected to electromagnetic linear motors by 6 rods of constant length

Experimental Approach
X-31 on MPM - ”Model Positioning Mechanism”

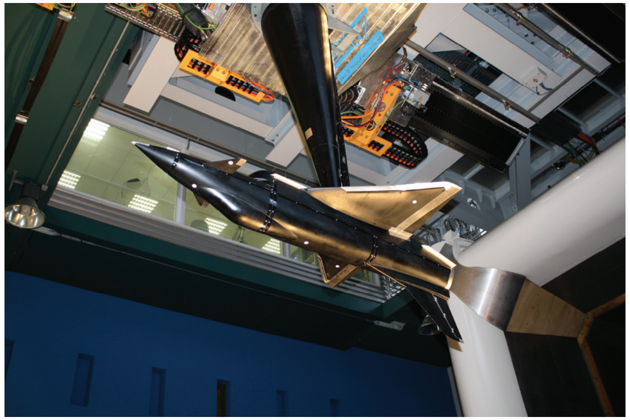
Pitch overlay



Pitch motion

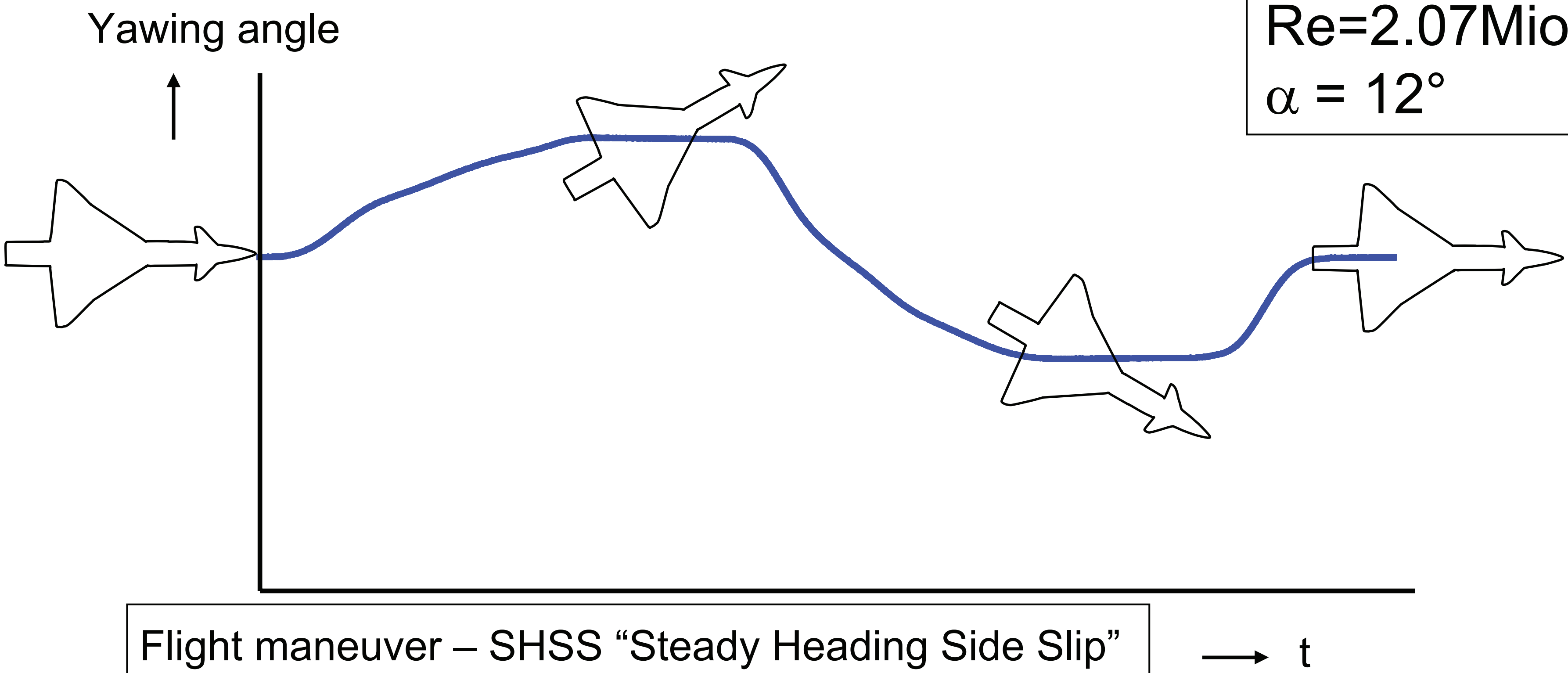


Yaw motion



Experimental Approach
X-31 on MPM - ”Model Positioning Mechanism”

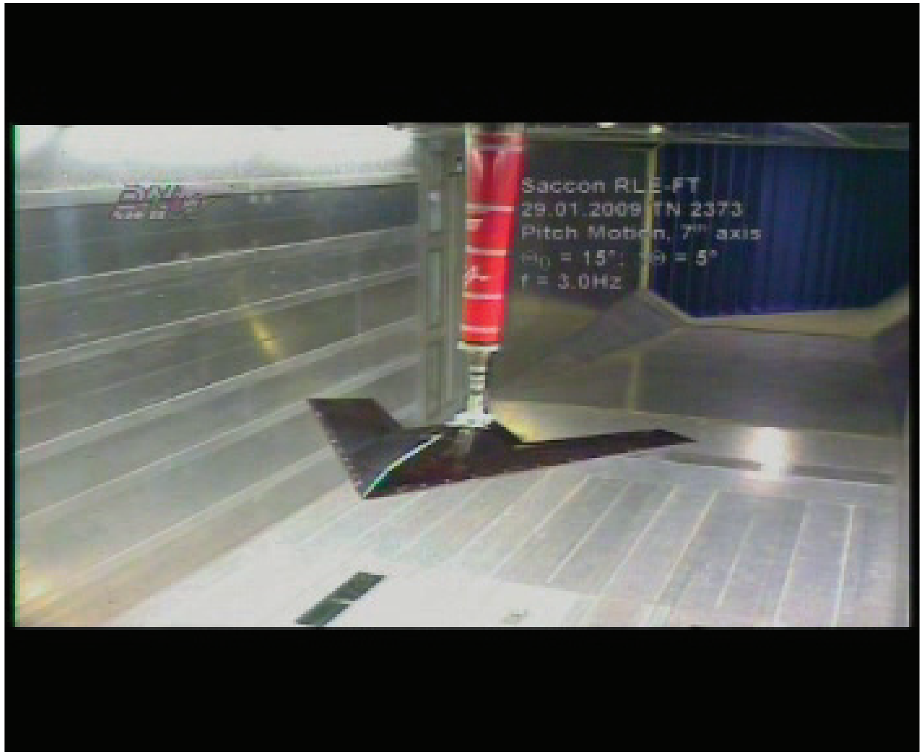
Ma=0.12
Re=2.07Mio
α = 12°

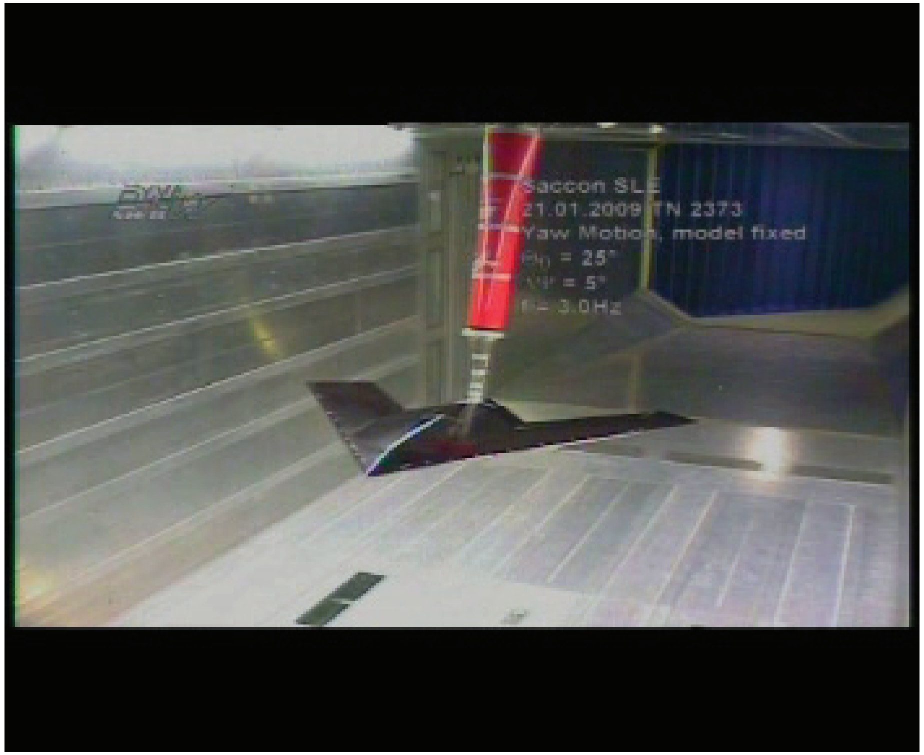


Flight maneuver – SHSS “Steady Heading Side Slip”

Yawing maneuver with constant angle of attack

Experimental Approach
DLR-F17 / NASA-SACCON model on MPM - "Model Positioning Mechanism"





German-Dutch Wind Tunnels

X-31 model results

α sweeps – Effect of sting support

Mode	alpha / °	beta / °	$\Delta\alpha/\Delta\beta$ / °	MPM	Date	Fuselage as in...	Remarks
α sweep	-5…15	0	1	Yaw link	04.11.2008	Figure 1	
α sweep	-5…15	0	1	Pitch link	06.11.2008	Figure 3	
α sweep	-5…30	0	1	Pitch link	12.11.2008	Figure 5	α from -5°…15° by MPM, then from 15°…30° by 7th axis
α sweep	-5…30	0	1	Pitch link	12.11.2008	Figure 5	α from -5°…15° by 7th axis, then from 15°…30° by MPM

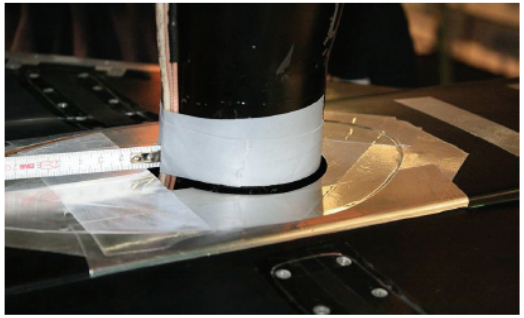


Figure 1: X31 fuselage bottom opening for yaw link

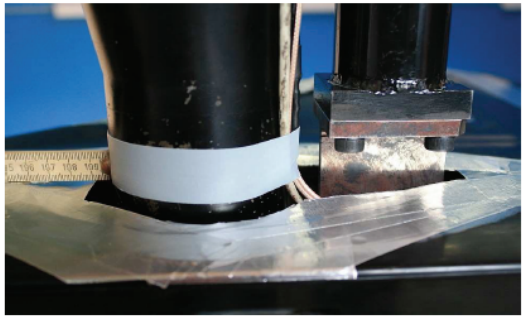


Figure 2: X31 fuselage bottom opening, pitch link $\Delta\alpha$ = 3°

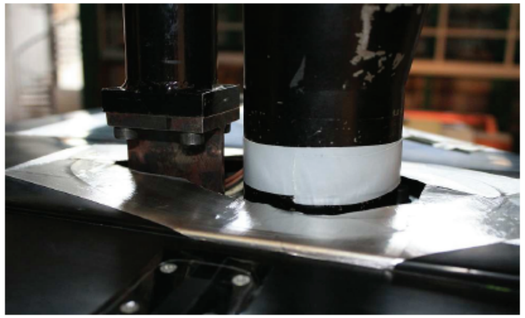


Figure 3: X31 fuselage bottom opening for pitch link $\Delta\alpha$ = 4°

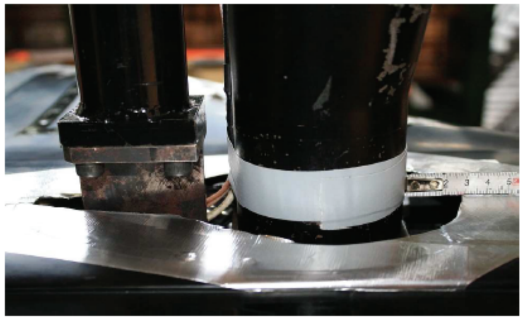


Figure 4: X31 fuselage bottom opening for pitch link $\Delta\alpha$ = 10°

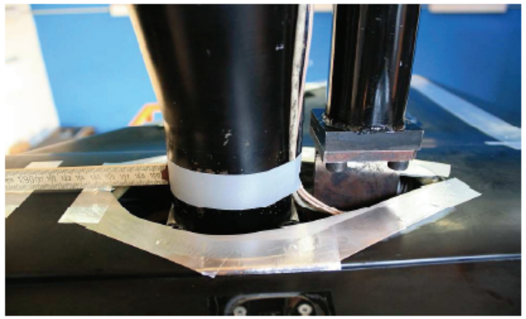
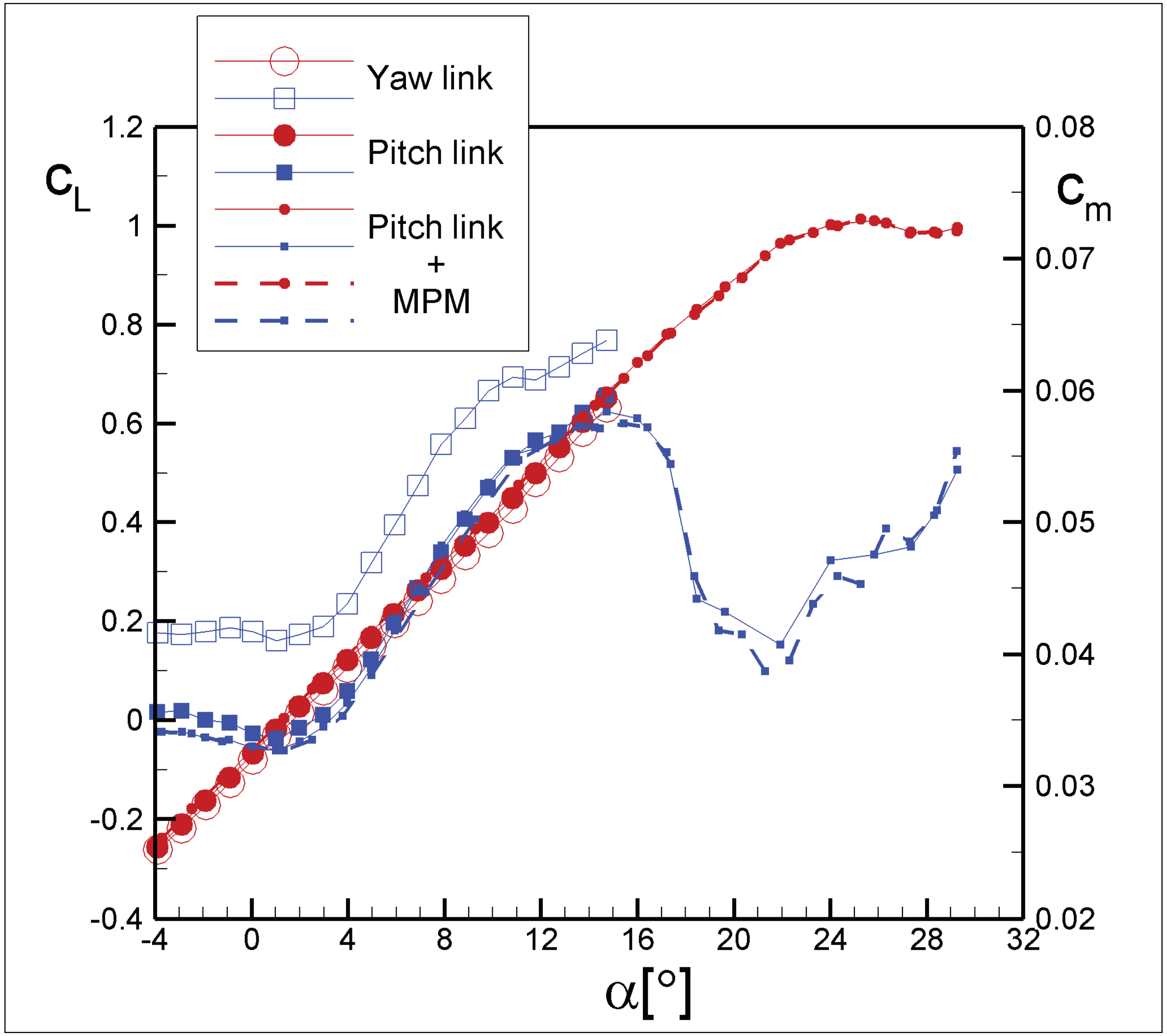
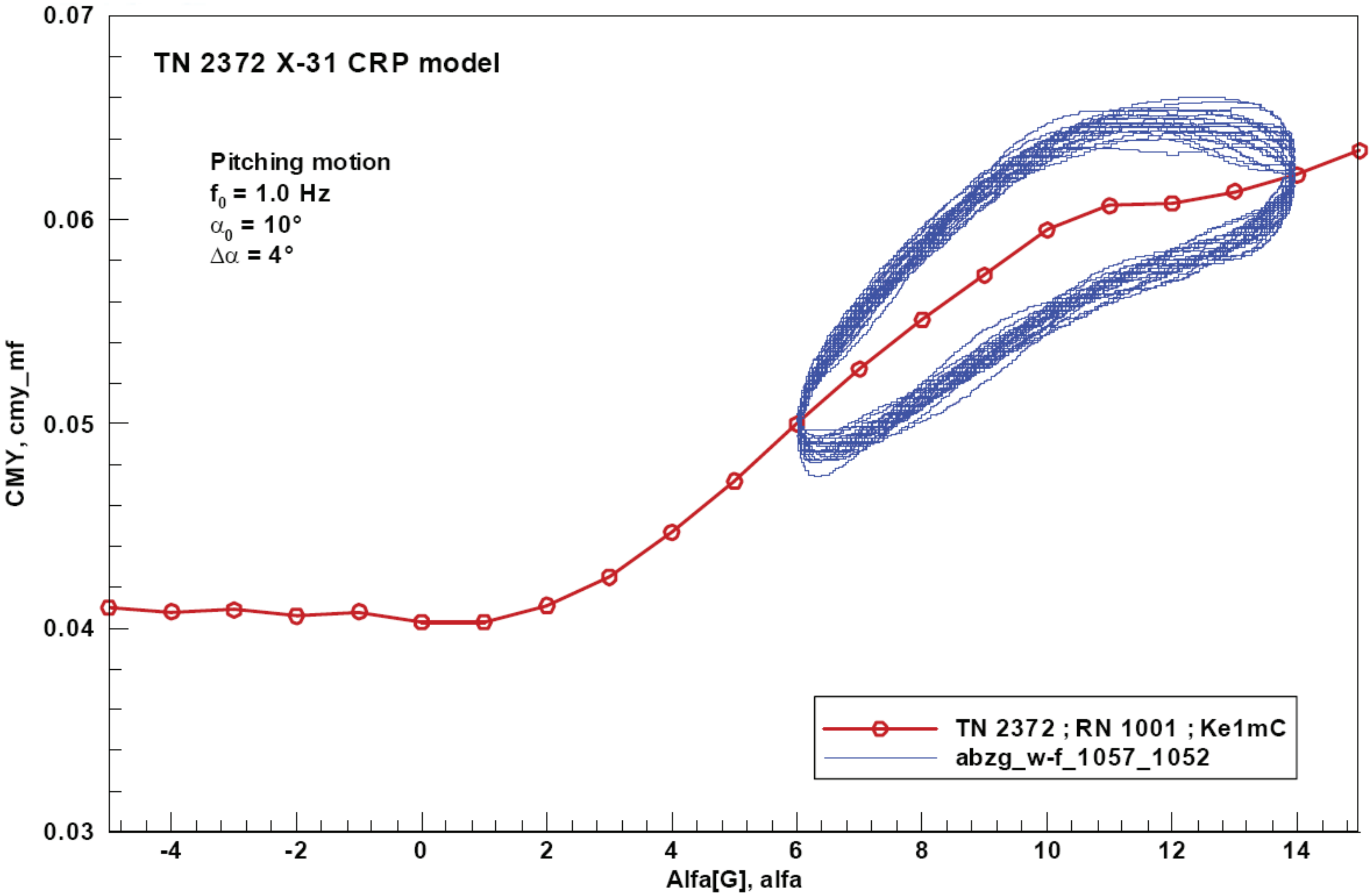


Figure 5: X31 fuselage bottom opening for pitch link $\Delta\alpha$ = 15°

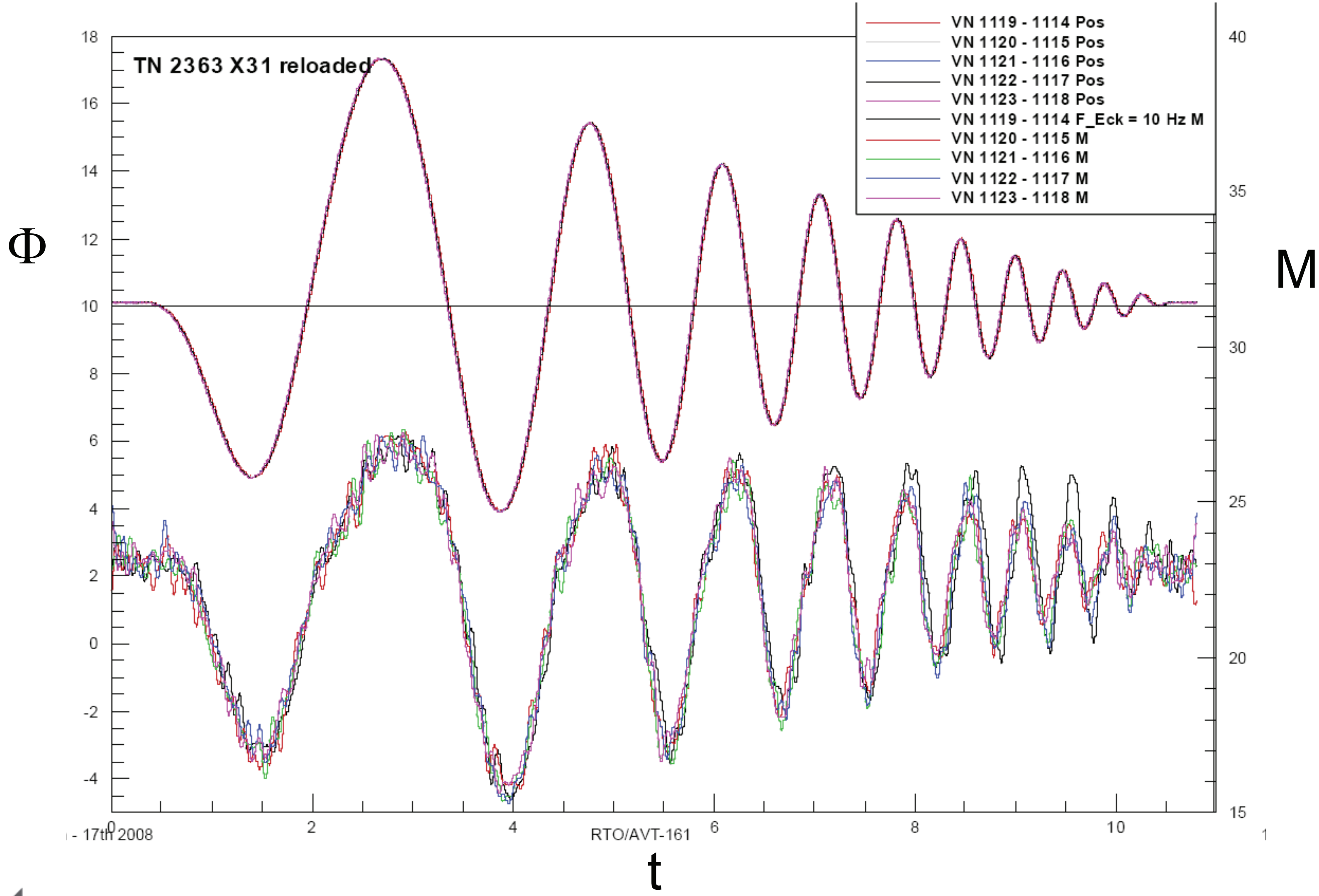
X-31 model results
α sweeps – Effect of sting support



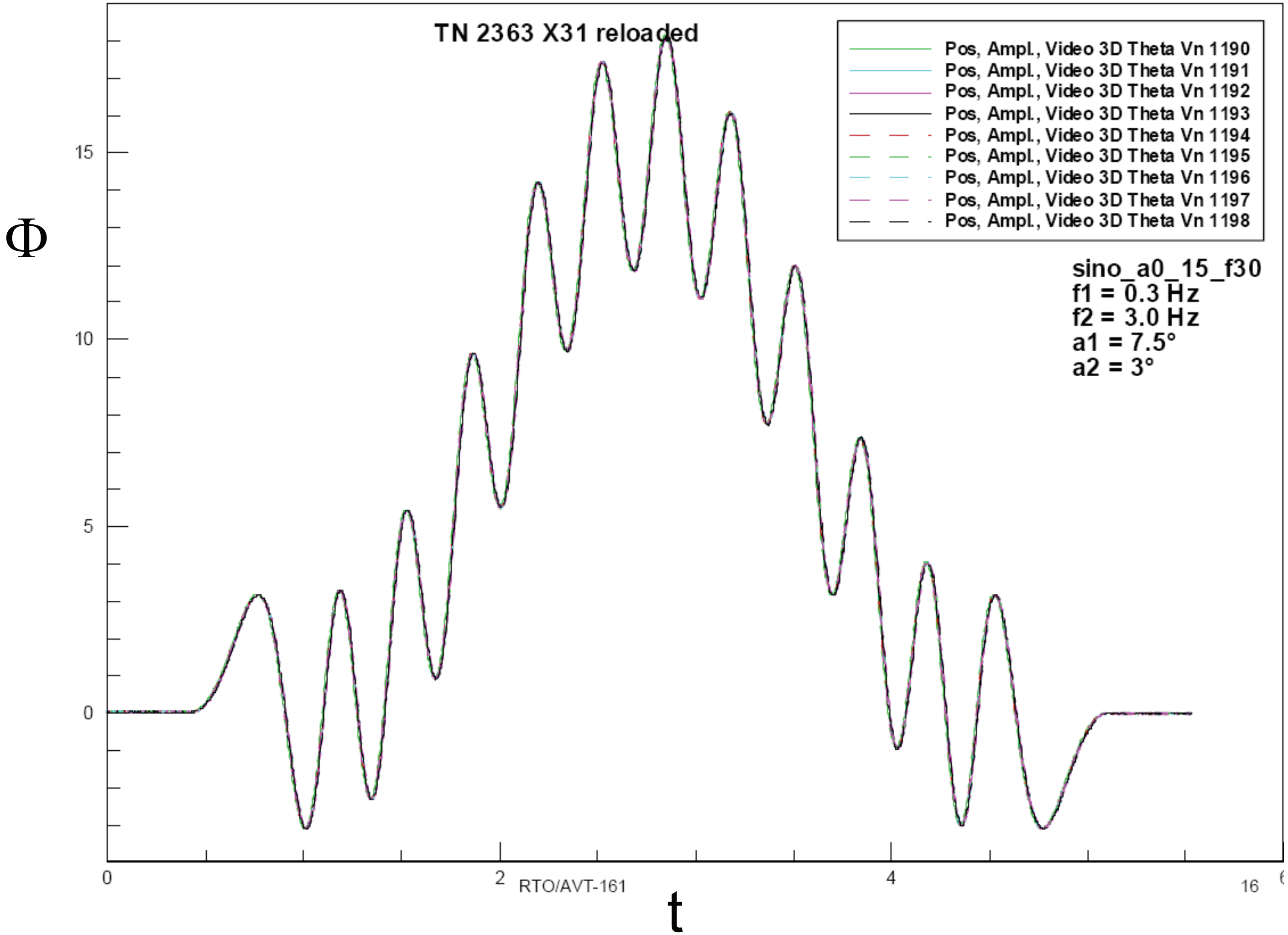
X-31 model results
Pitch Oscillation Data – static/dynamic



X-31 model results
Pitch Oscillation Data – Frequency ↑, Amplitude ↓



X-31 model results
Pitch overlay



Conclusions (1)

- In the last ten years unique test facilities for maneuver simulation are established at DNW in GÖ and BS
- Successful experimental and numerical demonstration of simulating
  - Rolling delta wing with control devices
  - full configured X-31 configuration in maneuver flight
  - UCAV configuration in pitch and yaw motion
- Synchronized data acquisition of
  - Model position
  - Balance data
  - Pressure sensors
  - Control devices
  - Dynamic PIV

Conclusions (2)

- Simulation of a complete complex maneuvers in the wind tunnel is still a challenging approach
- Data reduction, filtering and analyses are necessary to provide high accurate validation data
- The knowledge about
  - wind tunnel,
  - model setup
  - and test conditions is essential
- Coordination of the wind tunnel tests by both experimental and CFD experts is demanding